

Research Article

Camera Network Coverage Improving by Particle Swarm Optimization

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This paper studies how to improve the field of view (FOV) coverage of a camera network. We focus on a special but practical scenario where the cameras are randomly scattered in a wide area and each camera may adjust its orientation but cannot move in any direction. We propose a particle swarm optimization (PSO) algorithm which can efficiently find an optimal orientation for each camera. By this optimization the total FOV coverage of the whole camera network is maximized. This new method can also deal with additional constraints, such as a variable region of interest (ROI) and possible occlusions in the ROI. The experiments showed that the proposed method has a much better performance and a wider application scope. It can be effectively applied in the design of any practical camera network.

1. Introduction

Video cameras are widely applied to inspect and/or monitor interesting objects and scenes remotely and automatically [1, 2]. Often, to cover a large area, multiple cameras are connected together to form a camera/video network. By acting as an integrated unit, the camera network provides a much larger field of view (FOV) coverage than any single camera that constitutes it. However, the distribution of cameras (locations and orientations) will influence greatly the total FOV coverage of the camera network. With a fixed number of cameras, an optimal arrangement—putting cameras at the right locations and orientations—will produce the largest FOV coverage. It subsequently maximizes the effectiveness of the camera network deployment. This optimization problem has been studied by, for example, computer vision researchers from slightly different perspectives, such as 3D reconstruction [3, 4], target surveillance [5, 6].

The camera network FOV coverage optimization is defined as the using fewest possible cameras to monitor/inspect a fixed area or maximizing the FOV coverage of a network with fixed number of cameras. At present, the video camera is still an expensive sensor (not only in

terms of financial cost but also in terms of bandwidth and computation power needed for transmitting and processing its output). That is why the coverage optimization has attracted a lot of research attention [7]. The oldest coverage optimization may be the Art Gallery Problem (AGP) [8]. The goal of AGP is to determine a minimal number of guards and their positions, so that all important sites in a polygon area can be fully under supervision. Because the human guards have no eyesight limitations (in comparison to the limited FOV of video cameras), applying AGP directly to camera networks is difficult. Erdem and Sclaroff [9] defined a camera placement problem similar to AGP, but with a more realistic camera model. For solving this problem, they proposed a 0-1 integer program model for the placement and then adopted a bound and branch approach. However, it is very difficult, if not impossible, to globally optimize the formed mathematical model when the problem size becomes large. To avoid this problem, Hsieh et al. [10] limited themselves to several special types of scenarios (lanes and circles) and one type of cameras (omni directional).

Recently, more considerations from real applications are taken into account. For instance, unlike the previous mentioned papers trying to minimize the overlapping FOV,

Yao et al. [11] suggested that in some applications an overlapping FOV between the cameras is necessary. One such example is the object tracking. The trajectory of an object should be maintained across different camera views. For this purpose a sufficient uniform overlap between neighboring cameras' FOVs should be secured so that camera handover can be successful and automated. They proposed sensor-planning methods which add the handoff rate analysis. Zhao and Cheung [12] studied how to arrange the cameras for tracking visual tags. Their model incorporates realistic camera models, occupant traffic models, self-occlusion, and mutual occlusion possibilities.

The above-mentioned papers are about the full plan for deploying cameras in a network, where both location and orientation of each camera can be determined before constructing the network. Recently, Tao et al. [13, 14] studied another type of coverage optimization problem. In their system, the cameras were randomly spread over an area, the location of each camera could not be changed, but the orientation of each camera can be freely adjusted. Their system can be applied for military purposes where hundreds of cameras with wireless sensors are scattered by an airplane and quickly form a camera network to monitor a wide area. For large camera networks this system is more practical because in most situations the mounting locations are limited by the physical possibilities. Tao et al. proposed a potential field-based coverage enhancing algorithm (PFCEA) for solving this problem. In PFCEA, the FOV of each camera is regarded as a virtual particle and can be repelled by other cameras. The virtual force idea first appeared in [15], where it was used to deploy omni directional sensors. In [13, 14], if the virtual torque on the FOV of a camera is not zero, the camera will adapt its angle accordingly. They found the coverage of the camera network was maximized when the network reached an equilibrium.

In this paper, we base ourselves on the problem model and application of [13, 14]. Whereas, to overcome the disadvantage of the PFCEA algorithm (to be explained in Section 4), we propose to use particle swarm optimization (PSO) as the optimization engine. PSO was proposed by Kennedy and Eberhart to model birds flocking and fish schooling for food [16]. It is welcomed in practice, because it is easy to implement, needs few parameters, and does not require the objective function to be differentiable [17]. PSO has attracted a lot of research attentions in recent years. It has been successfully applied in, for example, training of neural networks [18], control of the reactive power and voltage [19], and cutting and packing problems [20]. We will show that PSO is also very effective for the camera network coverage problem. It can achieve global optimization. To prove its superior performance, we conduct an extensive comparison between PSO and PFCEA through several experiments. Further, we will theoretically analyze the optimization feasibility under different situations. We therefore find a new effective way for optimizing the camera network coverage problem that is much better than previous approaches. On the other hand, we explore a new field of applying the PSO algorithm.

Conci and Lizzi [21] also reported on the placement of cameras using PSO. In their method, they assumed

a Rayleigh distribution for characterizing the distance of the object and a Gaussian distribution for modeling the horizontal camera FOV, and, their work mainly focused on an indoor environment where the number of cameras is small and the PSO performance is not an issue. Our work, on the contrary, is more intended for applications discussed in [13, 14] where hundreds of cameras or more are randomly distributed in an unknown area. Therefore we focus more on the performance of the algorithm and the relationships between the coverage improvement and the scale of the network. This makes our work complementary to [21].

The paper is organized as follows. We first define our problem model in Section 2. We then introduce our PSO algorithm in detail in Section 3. Subsequently, we experimentally show the superior performance of our PSO algorithm and make comparisons to the PFCEA in Section 4. We then give discussions about the results in Section 5, and finally, we conclude the paper in Section 6.

2. Problem Model

2.1. Camera FOV. The FOV of a camera is defined as a fan-shaped area as in Figure 1, where CAB defines the FOV of a camera C. The length of CA or CB is denoted by R , which defines the distance from the camera to the most distant objects that appear with an acceptable resolution. The camera angle of view is denoted by 2α . The vector d defines the orientation of the camera and θ is the azimuth. We use (R, α) to note the type of the camera.

2.2. Camera Viewing Coverage. Under aforementioned camera FOV model, the viewing coverage c of a camera is defined as the ratio of the area of the FOV of the camera to the total monitored area S as $c = \alpha R^2 / S$. In the camera network, the observed regions of different cameras may be overlapped with each other. We use an approximate approach to calculate the coverage of a camera network. The total monitored area is divided into small regular grids. The coverage is then defined as the ratio of the number of covered grids to the total numbers of grids:

$$c = \frac{\text{number of covered grids}}{\text{total number of grids}}. \quad (1)$$

2.3. Camera Number versus Network Coverage. Suppose N cameras of the same type (R, α) are distributed randomly over an area S . The coverage c , defined in the previous subsection as a *probability* of the total area being covered, can be estimated as follows [9]:

$$c = 1 - \left(1 - \frac{\alpha R^2}{S}\right)^N \quad (2)$$

or

$$N = \frac{\ln(1 - c)}{\ln(S - \alpha R^2) - \ln S}. \quad (3)$$

Our simulations indeed showed that these equations are satisfied well for real situations. From (2) we can observe

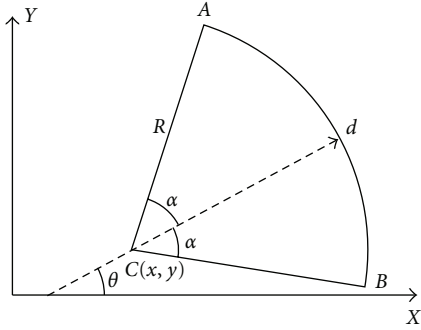


FIGURE 1: The FOV of a camera. The camera is located at C and oriented at θ . 2α is the camera angle of view. The fan area between CA and CB is the FOV of this camera.

that the expected coverage can be improved by adding more cameras. However, when N is large enough, adding more cameras is not effective any more. On the other hand, if we can adjust the orientation of the cameras to decrease the overlap of the VOF of the cameras, we can save a lot of cameras.

2.4. Coverage Optimization Problem. Suppose N cameras of the same type (R, α) are randomly distributed in a two-dimensional space. Each camera cannot change its location, but may adjust its orientation to any direction. A control center receives information about the orientations of all cameras and can adapt them accordingly (e.g., through the PTZ mechanism). The objective of the control center is then to determine the optimal orientations of all cameras, $(\theta_1, \theta_2, \dots, \theta_N)$, so that the total coverage of the whole camera network becomes maximized.

3. PSO for the Coverage Improvement

Our objective is to find the optimal orientation for each camera. But since the objective function (1) cannot be differentiated, the traditional gradient descent method will not work. PSO is a global optimizer which uses random search and does not require the objective function being differentiable. Moreover, it has shown good performance in many engineering optimization fields. Therefore we choose PSO to optimize the coverage of the camera network.

3.1. Concepts of PSO Algorithm. PSO was proposed by Kennedy and Eberhart (1995) to model birds flocking and fish schooling for food [16]. Since then it has been improved and applied in a lot of science and engineering fields. Similar to the genetic algorithm, a population of particles is used to search the solution space of an optimization problem. Each particle has a position vector and a velocity vector. The position vector is a potential solution of the optimization problem, and the velocity vector represents the step length of the update of the position. During the iterations of the PSO algorithm, all the particles vary their positions and velocities to search for the best solution. The optimal position found by the particles swarm is the final solution of the optimization.

The basic framework of PSO for optimizing an objective function $f(x)$ can be described as follows:

Step 1. Randomly generate m position vectors, x_1, x_2, \dots, x_m , each one is regarded as a particle and represents a potential solution of the optimization problem.

Step 2. Randomly generate m velocity vectors, v_1, v_2, \dots, v_m , where v_i is the step length for the update of x_i .

Step 3. Initialize m private best positions, p_1, p_2, \dots, p_m , by setting $p_i = x_i$, where p_i stores the best solution found by particle i during its history of updates. The evaluation of a position vector being best or not is based on $f(x)$, the objective function of the optimization problem.

Step 4. Initialize a global best position g , where g is the best among p_1, p_2, \dots, p_m .

Step 5. While the stop criteria are not satisfied,

- (1) for $i = 1, 2, \dots, m$, update each velocity vector v_i by
- (4)

$$v_i := C_1 \times v_i + C_2 \times \text{rnd}() \times (p_i - x_i) + C_3 \times \text{rnd}() \times (g - x_i), \quad (4)$$

- (2) for $i = 1, 2, \dots, m$, update each position vector x_i by
- (5)

$$x_i := x_i + v_i, \quad (5)$$

- (3) for $i = 1, 2, \dots, m$, reevaluate each position vector x_i , and set $p_i = x_i$ if x_i is better than p_i ,
- (4) set g to be the best among p_1, p_2, \dots, p_m .

Step 6. Output g as the final solution of the optimization problem.

In the above PSO algorithm, searching for the optimum is an analogy to the particle swarm flying in the space. The key step is to get the velocity vector by (4), which defines the step length of the position update during the search. C_1 , C_2 , and C_3 are constants and $\text{rnd}()$ is a random number in $(0, 1)$. Checking the right part of (4), we can see that v_i is composed of three components. The first one means that the flying is affected by the velocity in the last iteration. Therefore C_1 is often called the inertia factor. The second part means that the flying is affected by the private best position memorized by the particle. And the third part means that the flying is also affected by the global best position memorized by the system.

From (4) we can see that if the flying of each particle is attracted by the best particles found in the swarm, then a lot of exploitation will be performed near the best particle, and the convergence of algorithm can be assured. However, too fast convergence will make the algorithm fall into a local minimum. PSO uses the inertia factor and the $\text{rnd}()$ to make the particles deviate from directly flying to the temporary

- (1) Randomly generate mN -dimensional orientation vectors x_1, x_2, \dots, x_m , and mN -dimensional velocity vectors v_1, v_2, \dots, v_m . Then evaluate the coverage based on these orientation vectors and get the first private best position p_1, p_2, \dots, p_m and the global best g .
- (2) While the predefined iterations is not reached
- (3) for each particle $i = 1$ to m
- (4) calculate v_i as (4);
- (5) calculate x_i as (5)
- (6) transform x_i in to $[0, 2\pi)$ and evaluate the coverage based on x_i
- (7) if x_i is better than p_i , then update p_i .
- (8) if x_i is better than g , then update g .
- (9) end for
- (10) end while
- (11) output the global best position g , and the obtained coverage.

ALGORITHM 1: The PSO algorithm for the coverage optimization.

best particle. Then much more space around can be explored and the algorithm can jump out from a local minimum. This explains why the PSO generally has a good performance.

3.2. PSO for the Coverage Improvement. The “position vector” defined in the general PSO is a potential solution x when we optimize an objective function $f(x)$. The key problems for applying PSO are to define the position vector x and the objective function $f(x)$. To avoid confusion, we use for the cameras the terms “locations” and “orientations” instead of the “positions” throughout this paper.

In our coverage improvement problem, we need to optimize the orientation vector of the cameras, $x = (\theta_1, \theta_2, \dots, \theta_N)$. The objective function is the total coverage defined in (1). The computation of (1) is based on the orientations, locations, and the type parameters (R, α) of all cameras. The locations and the type parameters of the cameras are the inputs to the algorithm. The orientations are what will be searched for. For all the experiments, we follow [22] to set $C_1 = 0.729$ and $C_2 = C_3 = 1.49445$ in (4).

In standard PSO, the velocity v is often bounded in a range of $(-V \max, V \max)$ to avoid a long jump of x that may result $x(i)$ missing the optimum. In our experiments, we do not limit the velocity, but transform the orientation of the camera to a value in the range of $[0, 2\pi)$. Then the update of the x is also bounded.

The algorithm will stop when the number of iterations is equal to a predefined number, or a predefined coverage is reached. Because the locations of the cameras are randomly generated, we cannot predefine the coverage. Therefore in practice we often use a predefined maximum number of iterations. The complete algorithm is listed in Algorithm 1.

4. Experiments and Results

Three experiments were carried out to demonstrate the performance of the PSO for the coverage improvement of cameras. In Experiment 1, the performance and convergence of PSO were studied. In Experiment 2, PSO and PFCEA were compared to each other and the advantages of PSO

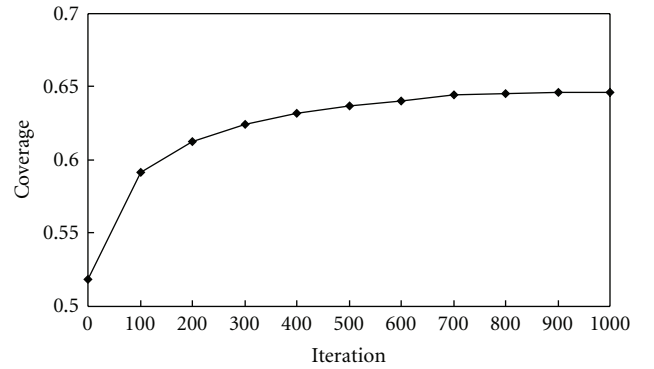
FIGURE 2: The convergence curve of PSO on a 500×500 area with 150 randomly distributed cameras.

TABLE 1: The statistical data about the coverage improvement.

Algorithm	Mean	Stdvar
PSO	0.13	0.009
PFCEA	0.07	0.018

were shown by the statistical data. In Experiment 3, the relationships between the coverage improvement and the configuration of the camera networks, including the number of the cameras and the type parameters of the cameras, were investigated.

Experiment 1. In this experiment, the monitored area was set to be a 500×500 rectangle, and 150 cameras were randomly distributed in the rectangle. Each camera was of type $(R = 40, \alpha = \pi/4)$. To calculate the coverage, the rectangle was divided into 500×500 unit grids. For the PSO algorithms, 20 particles were used and the max iteration number was set to 1000.

The global best coverage found in the first iteration was 0.52. After 1000 PSO iterations, the coverage was improved to 0.65. The convergence curve is displayed in Figure 2. The pictures of the initial layout and the final layout of the camera network are shown in Figure 3.

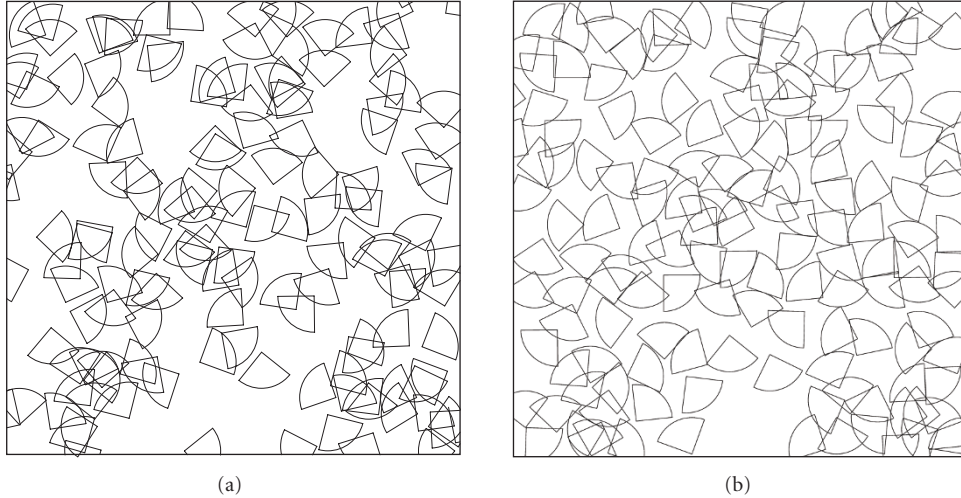


FIGURE 3: The coverage improvement of the PSO. (a) the initial layout. (b) The final improved layout.

As indicated by (2), 150 cameras are expected to reach the coverage of 0.53. Our initial placement with the coverage of 0.52 was close to this. After the 1000 cycles of PSO, the coverage was raised to 0.65, that is, the coverage was improved for about 0.13. If we want to get this coverage without optimization, we will need to add another 58 randomly placed cameras (total of 208 cameras) as can be seen in Figure 2. In other words, we have saved 58 cameras by improving the coverage using the PSO.

Note that the improvement of the coverage varies with respect to the random initial configuration of the network, but in Experiment 2 we will show that the coverage improvement of the PSO is often stable.

Experiment 2. To show the performance of the PSO further, we ran the program for 30 runs with the same camera number, camera type, and PSO parameters as in Experiment 1. We collected the coverage improvement data, where each run started from a random initial configuration. We also implemented PFCEA as described in [9, 10] to make a comparison. In PFCEA, if the virtual torque was greater than 10^{-6} , the camera was rotated for $\pi/180$, otherwise the camera was regarded to be in equilibrium. The iteration of PFCEA was set to 360 in order for each camera to rotate for a full round (Our experiences also showed that 360 iterations are enough for the convergence of PFCEA, and more iterations did not improve the coverage any more.) The collected statistical data about the coverage improvement is shown in Table 1. From this we conclude that our PSO statistically more significantly improved the coverage than PFCEA and the performance was more stable.

Actually, because of the limitation of the underlying principle employed, Tao et al.'s PFCEA algorithm cannot achieve the best possible optimization in a camera network. As illustrated in Figure 4(a), the two cameras are in equilibrium but the coverage of the two cameras is not as large as in Figure 4(b). In view of the optimization, PFCEA tries to use the virtual force as the gradient to search for

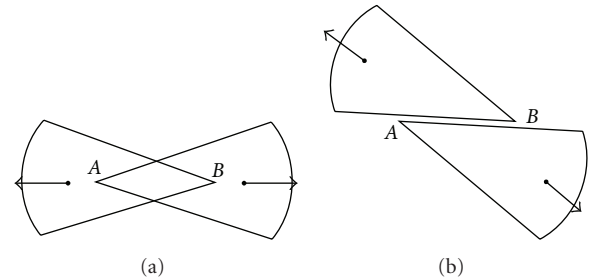


FIGURE 4: An illustration of the disadvantage of PFCEA algorithm. (a) Since the two cameras are not allowed translational movement, they are in a balance state. This configuration is considered as the optimal solution by PFCEA but it is not really optimal because of the existence of overlaps. (b) A possible state with maximal coverage.

the orientations, but because the cameras cannot move, its optimization ability is always limited.

Experiment 3. In this experiment, the relationships between the coverage and the three parameters N , R , and α were investigated, and our PSO algorithm was further compared with the PFCEA of Tao. In each calculation, the positions of all the cameras were randomly generated and fed to PSO and PFCEA identically. The settings for PSO and PFCEA were the same as in Experiments 1 and 2.

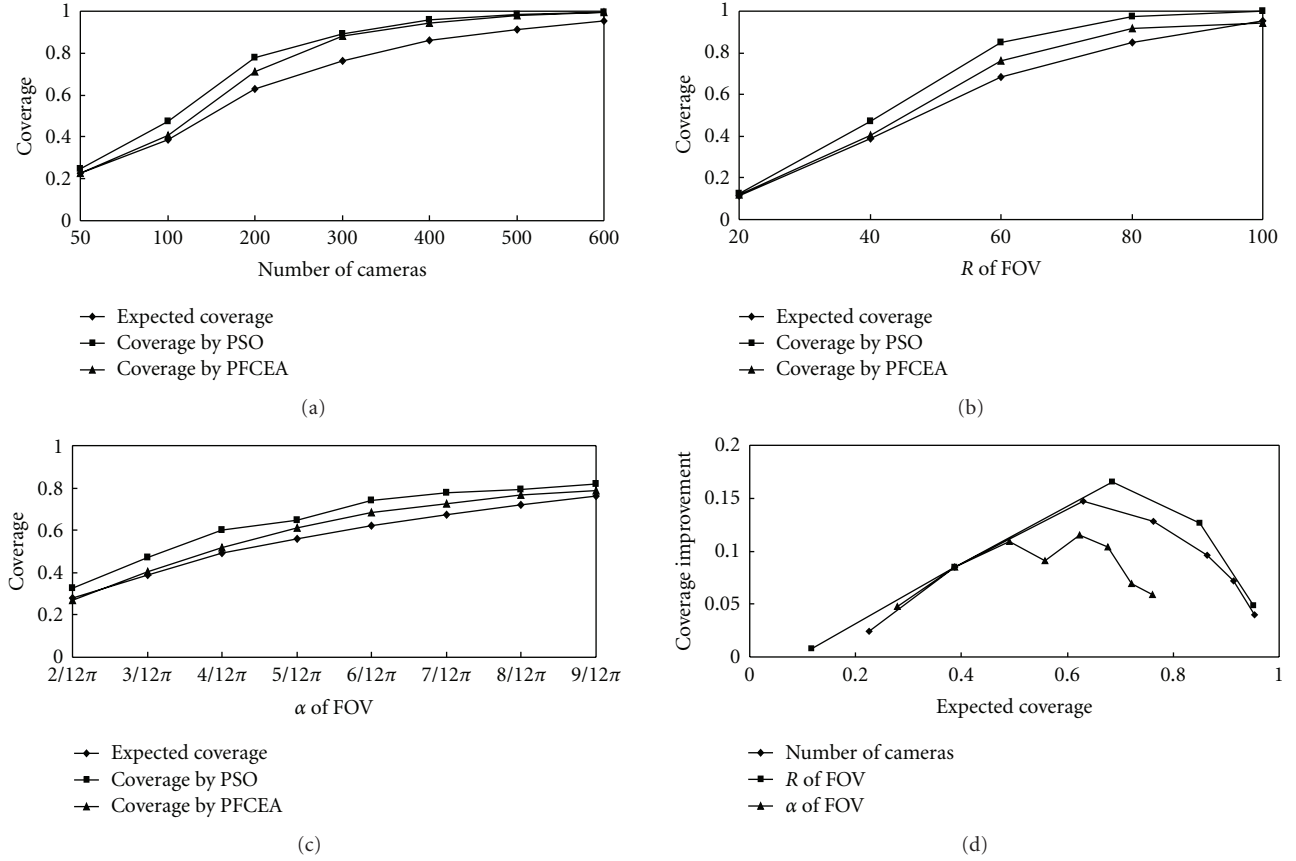
The experiment was carried out in three phases with marginally varying the 3 parameters. Firstly we varied N , keeping R , and α fixed. Then we varied R , keeping N , and α fixed. Finally we varied α , keeping instead N and R fixed. The parameters of the camera networks are shown in Table 2, the results are illustrated in Figure 5.

The main results that we can conclude from Figure 5 are the following.

- (a) PSO performed better than PFCEA in all three phases. In mostcases, the coverage improvement of

TABLE 2: The parameters of the camera networks in Experiment 2.

	S	N	R	α
Phase 1	500×500 rectangle	Varied from 50 to 600	40	$\pi/4$
Phase 2	500×500 rectangle	100	Varied from 20 to 100	$\pi/4$
Phase 3	500×500 rectangle	100	40	Varied from $\pi/6$ to $3/4\pi$

FIGURE 5: The relationships between the parameters and the coverage. (a) Relationship of (c, N) ; (b) relationship of (c, R) ; (c) relationship of (c, α) ; (d) relationship of the coverage increment by PSO and the initial coverage.

PSO was nearly twice as large as that of PFCEA. We believe that this is because PSO is a global optimization technique and the global coverage is the objective of this optimization. In contrast, the objective of PFCEA is balancing the virtual torque and the optimization of coverage is indirect. Therefore no global optimal coverage can be obtained. That is why in some rare cases PFCEA even decreases the coverage, as can be seen in Figure 5(c) (camera angle of view equal to $2/12\pi$, the initial coverage equal to 0.279, and after the processing of PFCEA, the coverage became 0.267).

(b) when the initial coverage was very small or very large, the improvement was small. This finding was first claimed in [9], and consistent with the experiments in this paper, as shown in Figure 5(a), 5(b), and 5(c). The reason to this is that if the initial coverage

is very small, the overlap between the FOV of the cameras will also be small in general, and then the improvement cannot be very large. A contradictory case is that the small initial coverage is caused by the heavy overlap of FOV, but because the initial deployment is random, the coverage should obey (2), then this special case rarely appears. On the other hand, when the initial coverage is very large, there is little space left for improvement, and then it is impossible for any algorithm to find large uncovered spaces.

(c) to get a clearer picture about the relationship between the initial coverage and the coverage improvement, we used the initial coverage as x -axis and the coverage improvement as y -axis, and we got three curves as in Figure 5(d), which are derived from Figures 5(a), 5(b), and 5(c). We can observe again that, when

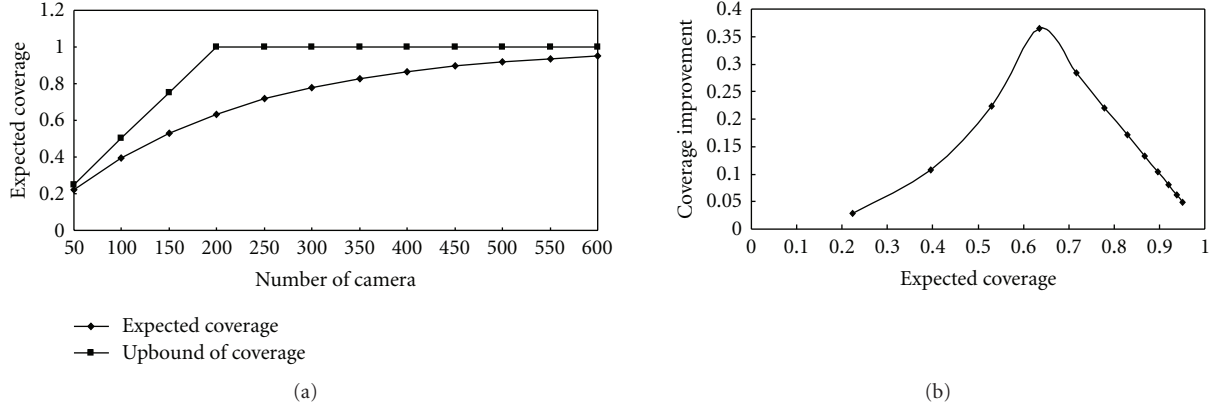


FIGURE 6: Relationship of the coverage improvement and the expected coverage. (a) Curves of expected coverage, upper bound of coverage; (b) relationship of the expected coverage and the coverage improvement.

the initial coverage was too small or too large, the improvement was small. When the initial coverage was near 0.6, the PSO obtained the greatest coverage improvement.

5. Discussions

5.1. The Expected Coverage for the Probably Maximal Coverage Improvement. The experiments in the previous section demonstrated that the PSO can improve the coverage the most when the initial coverage is about 0.6 but has less effect when it is close to 0 or 1. Considering that we can get the expectation (expected coverage) of this initial coverage by (2), we will explain the results theoretically. That is, we want to show that when the expected coverage is near 0.6, there will be maximum space for the improvement.

Assuming that there is no overlap between any two cameras in a camera network, we have a maximum covered area. Therefore, we can define the upper bound of the coverage (c_{ub}) of N cameras in type of (R, α) as follows.

$$c_{ub} = \min\left(\frac{N\alpha R^2}{S}, 1\right). \quad (6)$$

With (2) and (6), we then have an upper bound of the coverage improvement

$$\text{delta}_{-c_{ub}} = \min\left(\frac{N\alpha R^2}{S}, 1\right) - \left(1 - \left(1 - \frac{\alpha R^2}{S}\right)^N\right). \quad (7)$$

Let us consider the relationship of $\text{delta}_{-c_{ub}}$ and N with (R, α) and S being constant. From (7) we can conclude that $\text{delta}_{-c_{ub}}$ is a monotonically increasing function of N when $N\alpha R^2/S \leq 1$, and a monotonically decreasing function when $N\alpha R^2/S \geq 1$. Then we get the maximum improvement when $N\alpha R^2/S = 1$.

Replacing $\alpha R^2/S$ with $1/N$ in the expected coverage (2),

$$c = 1 - \left(1 - \frac{\alpha R^2}{S}\right)^N = 1 - \left(1 - \frac{1}{N}\right)^N. \quad (8)$$

We know that when N is large enough (e.g., above 100 in this paper), $(1 - (1/N))^N \rightarrow e^{-1}$ yielding $c = 1 - e^{-1} = 0.635$. This means that when the expected coverage near 0.6, we could get the maximum coverage improvement. This value is close to our observations from the experiments.

In Figure 6(a) we plot the expected coverage c and the upper bound of the coverage c_{ub} as the function of N , where S is set to 500×500 , cameras are of type $(R = 40, \alpha = \pi/4)$. From this figure we derive Figure 6(b) in which we plot the coverage improvement $\text{delta}_{-c_{ub}}$ as a function of the expected coverage c . In Figure 6(b), we can clearly see that the upper bound of coverage improvement is small when the expected coverage is near 0 or 1, and is maximal when the expected coverage is near 0.6.

5.2. Adaptive ROI with the Proposed PSO. PFCEA adjusts the orientations of the cameras to enlarge the FOV of the camera network. However, the larger FOV does not always mean higher coverage. Some applications need the camera network to cover a special region of interest (ROI). As PFCEA cannot relate the ROI with the FOV of the camera network, new approaches must be developed. In our proposed PSO, ROI and FOV are related by (1), so our method can work well without any modification.

Always, constraints should be considered in real applications, such as ROI differences, and the occlusions by obstacles. We still assume that the cameras are already installed, and we are required to adjust orientations of the cameras to improve the coverage of the network. Given that areas that are not in the ROI need not be covered, the definition of coverage is changed into

$$c = \frac{\text{number of covered grids in ROI}}{\text{total number of grids}}. \quad (9)$$

(a) Different ROI at Different Time. In some applications, the ROI of the system varies depending on the surveillance objective. For example in Figure 7, two cameras installed on the wall should monitor A_1 (working area) in the daytime,

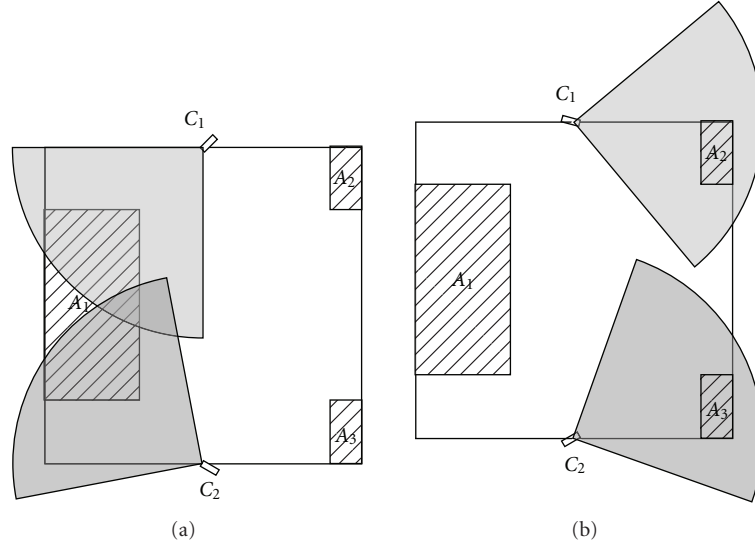


FIGURE 7: The results of PSO for different ROIs. (a) Two cameras C_1 and C_2 are arranged to monitor A_1 in the daytime. (b) They monitor A_2 and A_3 in the night.

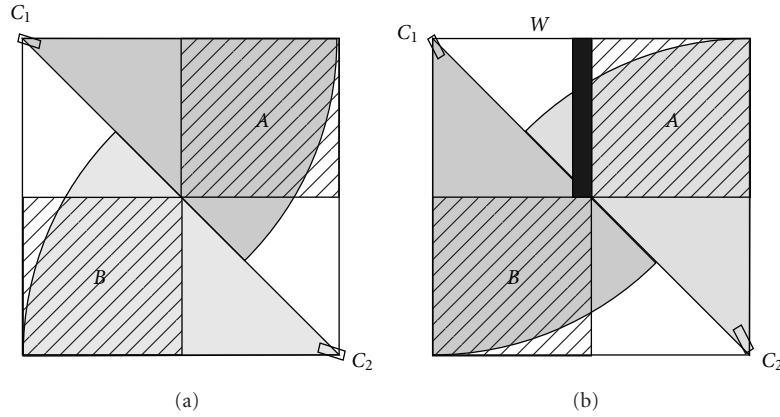


FIGURE 8: The results of PSO when ROI is occluded. (a) Camera C_1 monitors A and camera C_2 monitors B . (b) When the obstacle W appears, PSO finds new orientations for the two cameras.

monitor A_2 and A_3 (two doors) in the night. The size of room is 100×100 . The area A_1 is a rectangle of 30×60 and located near the center of the western wall. The area A_2 and A_3 are rectangles of 10×20 and located at the two corners beside the eastern wall. Two cameras C_1 and C_2 are of type ($R = 60$, $\alpha = \pi/2$) and installed at the center of northern and southern wall of the room.

Then we can use PSO to compute the optimal orientation of the two cameras in the two periods. The results are listed in Table 3, and shown in Figures 8(a) and 8(b) illustrating the solution in the daytime and the night. Note that because the ROI in the daytime and in the night is different, we cannot compare the coverage in the two cases.

(b) ROI Is Occluded by Obstacle(s). In this example shown in Figure 8, a room of 100×100 is monitored by two cameras C_1 and C_2 , where C_1 located at the northwest corner and C_2 located at the southeast corner and both cameras are of type

TABLE 3: The orientations of the cameras by PSO for different ROI.

	Orientation of C_1 (radians)	Orientation of C_2 (radians)	Coverage
Day time	2.330290163	3.732819163	0.2234
Night	0.128384856	5.845456163	0.0410

($R = 100$, $\alpha = \pi/4$). The ROI is the area occupied by two rectangles A and B with the same size of 50×50 .

At first, we get a solution by PSO as in Figure 8(a), where camera C_1 is arranged to monitor area A and camera C_2 is arranged to monitor B . Figure 8(b) shows the solution when an obstacle W appears in the room and the initial FOV of C_1 is occluded. As a result, the PSO provides a new solution, letting C_1 monitor B and C_2 monitor A . The results are listed in Table 4. We note that the coverage is maintained after the adjustment of the orientations of the two cameras.

TABLE 4: The orientations of the cameras by PSO for obstacles.

	Orientation of C_1 (radians)	Orientation of C_2 (radians)	Coverage
No obstacle	0.384704775	3.524939082	0.4475
Obstacle W	1.182262775	4.322527082	0.4475

6. Conclusions

In this paper, we proposed a PSO algorithm to greatly improve the coverage of a camera network in which the orientation of each camera can be freely adjusted. Our results showed that the coverage can be greatly improved by adjusting the orientation of each individual camera. In this way we may save a large amount of cameras. The algorithm can improve the coverage the most when the initial coverage is about 0.6. But it has less effect when the initial coverage is near 0 or 1. Our way of optimizing the camera network coverage problem outperforms current solutions from PFCEA. We also showed that our approach can deal with variable ROIs and with occlusions. Our findings suggest that the optimization of orientations of cameras should attract more attentions in the design of camera networks. We further believe that the method provided in this paper can be applied in the camera networks to adjust not only the orientation but also the position of the camera.

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